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ScienceDirect
Procedia Engineering 73 (2014) 345 – 351
Procedia Engineering
www.elsevier.com/locate/procedia

Geological Engineering Drilling Technology Conference (IGEDTC), New International Convention Exposition Center Chengdu Century City on 23rd-25th May 2014

Optimal Design of the Flow Field of Bi-center Bit

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Abstract

Bottom-hole flow field is determined by the hydraulic structure of PDC bit, it is one of the important factors that affect the performance of the bit. The flow field optimizing is an important means of improving the hydraulic performance of drill bit. Because of the complicated structure, the performance of bi-center bit is different from conventional bit, thus its flow field is necessary to be optimized. In this paper, an evaluation method of the bottom-hole flow field of the bi-center bit is proposed, the relationships between flow distribution, nozzle angle and cuttings carrying effect are studied with numerical simulation method, the reflux distributions of the bottom-hole flow field are obtained under the different combinations of different size nozzles and nozzle spray angles, the hydraulic structure of the bit is optimized according to the numerical simulation results, then an optimal hydraulic structure of bi-center bit is obtained

Keywords: bi-center bit,flow field,flow distribution, reaming section spray angle

1. Introduction

Bi-center bit is composed of piloted section and reaming section, which is different from conventional drill bits, as shown in Fig. 1. Because of the complicated and asymmetric structure, there are lots of differences between bi-center bit and conventional bit. The piloted section is same with conventional bit. Reaming nozzles are installed in the reaming section along the reaming direction, which are used to clean the cuttings produced by two main blades. The flows from the piloted section and the reaming section meet at the transition area between the piloted section and the reaming section where a hydraulic transition zone is formed[1].

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doi:10.1016/j.proeng.2014.06.208

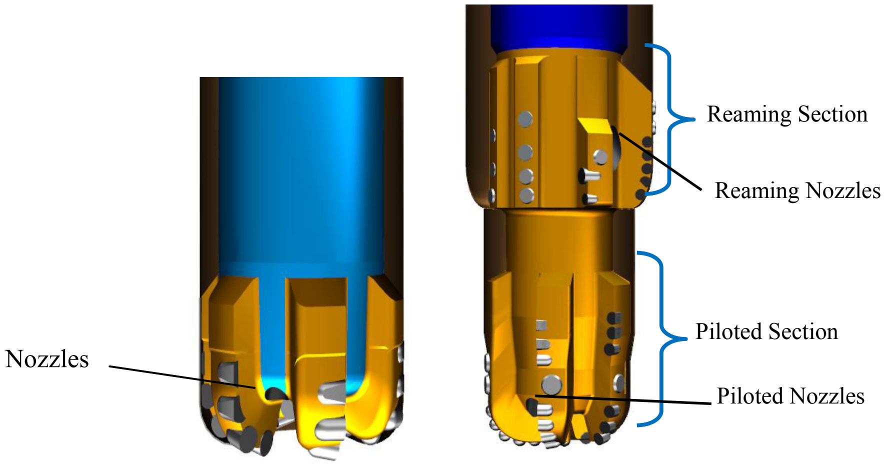


Fig. 1. (a) conventional bit; (b) bi-center bit used in directional drilling

Cuttings carrying effect is a main criteria for the evaluation of conventional bit. Because of the special structure, bi-center bit has a flow distribution problem between the piloted section and the reaming section, which is different from conventional bit. Because of the different rock-breaking areas, the flows needed by the piloted section and the reaming section are different, the actual flow distribution would affect the cuttings carrying effect of the bit. Unreasonable flow distribution would form an interference area between the two flow fields, then a reflux would be formed, it would cause that cuttings repeated broken in the bottom vortex, thus affect the drilling efficiency and cuttings carrying effect[2~3].

Based on the analysis of flow field, an evaluation criterion of bi-center bit is proposed, the flow field is simulated with the numerical simulation method, the flow field is evaluated under the evaluation criterion, the distribution of the reflux is obtained under the combinations of different size nozzles and nozzle spray angles, it would provide a basis for the hydraulic structure optimizing of bi-center bit.

2. The evaluation method of bottom-hole flow field

A good bottom-hole flow field is good for borehole cleaning and cutting carrying[4,5]. According to the special hydraulic structure, while evaluating a bi-center bit based on the evaluation criteria of conventional bit, the following aspects should be considered:

- Flow distribution should match with rock breaking area

Due to the different rock breaking areas, the amounts of cuttings produced by piloted and reaming section are different, thus the amounts of needed drilling fluid used for cuttings carrying and bit cooling are different. To ensure the cuttings carrying capacity, the flow distribution between the two sections should match with the rock breaking areas.

- Reflux area in bottom hole flow field

Due to the downward direction of the jet nozzle in the reaming section, it would oppress the upward flow from the piloted section, then a reflux would be formed, which would cause that cuttings repeated broken in the bottom vortex, thus affect the drilling efficiency and cuttings carrying effect. Therefore the size of the reflux area is an important evaluation criterion of bi-center bit flow field. Streamlines represent the movement of the fluid particles in the same streamline in the instantaneous flow field, and reflect changes in the flow field, the size of the area can be determined from the distribution of streamlines in the flow field.

3. Simulation method of the bi-center bit flow field

In order to get and evaluate the flow field distribution of a bi-center bit, a flow field of a bi-center bit used in directional drilling is simulated using CFD software. FLUENT is a hydrodynamic software characterized by easy operating and accurate computation, so in this paper it is used to simulate a bottom hole flow field.

Take a bi-center bit for example, its structural parameters are as follows: piloted section diameter is 125mm, the target hole diameter is 136mm, eventually expanding radius is 82.5mm, inner bit flow channel diameter is 30mm, length of the transition zone is 55mm. Numerical simulation consists of the following steps:

- Establish geometric model

A three-dimensional model of a bit is built using UG or Solidworks software. Assuming the bit invasion depth is the same as exposed height of cutting tooth, thus cutting teeth modeling can be omitted. A borehole model is built according to the actual working conditions of the bit. Based on Boolean calculation, a three-dimensional flow space model is established between the bit and borehole, Fig.2.

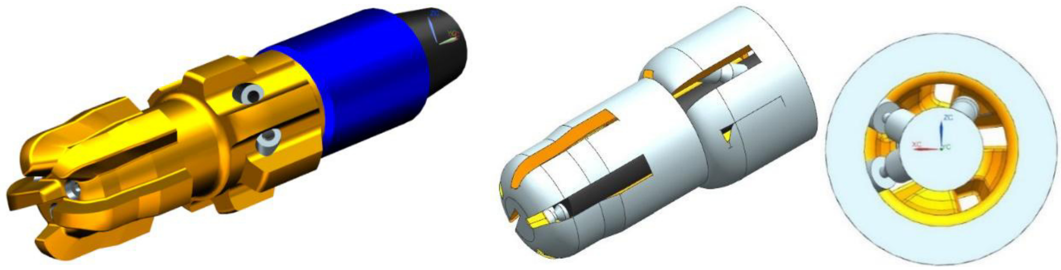


Fig. 2 Bi-center bit and the flow field model

- Meshing

In this paper, due to the complicated structure, the computational domain of bi-center bit is divided in the form of unstructured grids, and in order to save computing time tetrahedral structures grid is selected for meshing.

- Boundary conditions and other parameters

Assuming the hole depth is 1000m, reference flow rate is 10~16 L/s, working flow rate is 15 L/s, flow velocity is 12 m/s. Set outlet flow condition as a non-refluxing outlet boundary condition, set drilling fluid column pressure as 12 MPa. Set the calculated medium as drilling fluid, density is 1200 kg/m3, viscosity is 0.035 kg/ms.

4. Simulation results and analysis

Using numerical simulation methods bottom hole flow field of bi-center bit is obtained. Through analysis and comparison of the bottom hole flow field streamlines (Fig. 3) and the cross-sectional velocity clouds at different locations (Fig. 4), some of the results are obtained.

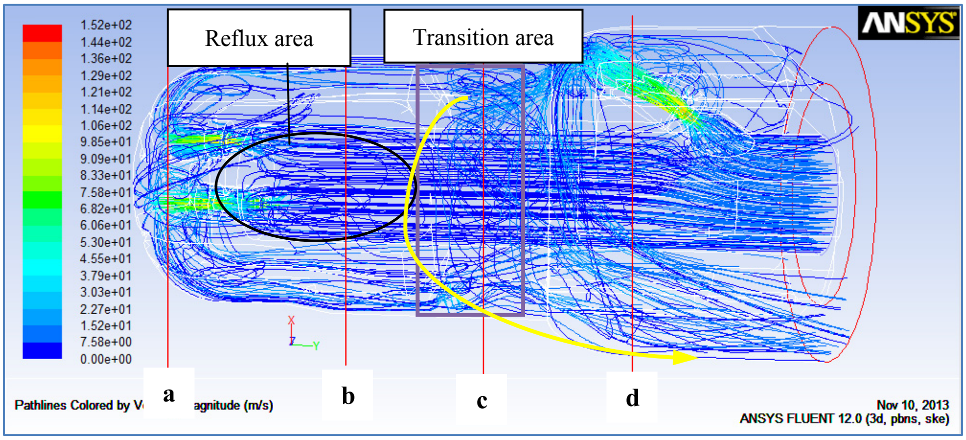


Fig. 3 Bottom hole flow field streamlines

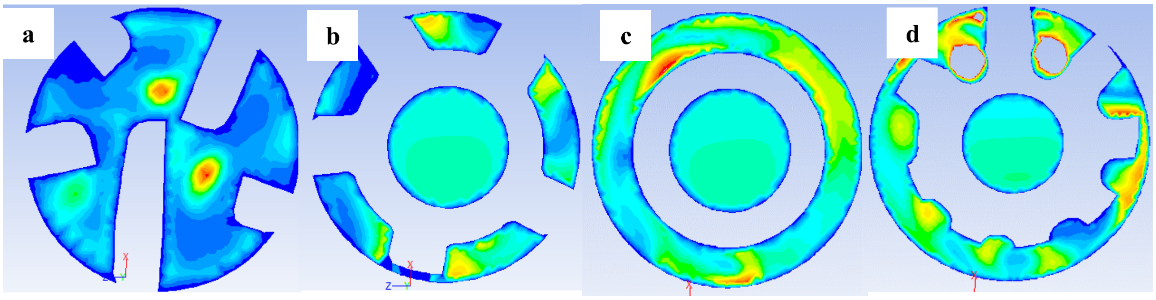


Fig. 4 Cross-sectional velocity clouds at different locations

4.1. Bi-center bit flow field characteristics analysis

As shown in Fig. 3, the flow field of piloted section is similar to conventional bit, drilling fluid flows upward after blowing out from nozzles. In the reaming section, after blowing out from the nozzles, a portion of the fluid flows upward along the borehole wall, most of the flow moves downward along the borehole wall and generate interference with the flow comes from piloted section at the transition area, then flows to the contralateral direction of reaming blades, finally flows upward with the undisturbed flow along the borehole wall. Part of the flow from the piloted section is disturbed by the flow from reaming section, which generates a reflux in some local areas.

As shown in Fig. 4a, the flow from piloted section generates a high speed overflow layer in the bottom, which ensures the cuttings is moved from the center to the edge of the bit. Fig. 4b is a cross section of the upper piloted section, disturbed by the local reflux, the velocity distribution is uneven. Fig. 4c is a cross section of the transition area, since the intersection of interference flow field, the most serious interference area has a high flow rate. Fig. 4d is a cross section of reaming section, in addition to the high and uneven flow rate around the nozzles, due to the flow field has gathered, the velocity of the other part is more uniform.

4.2. Influence of the different distribution between the piloted and reaming section

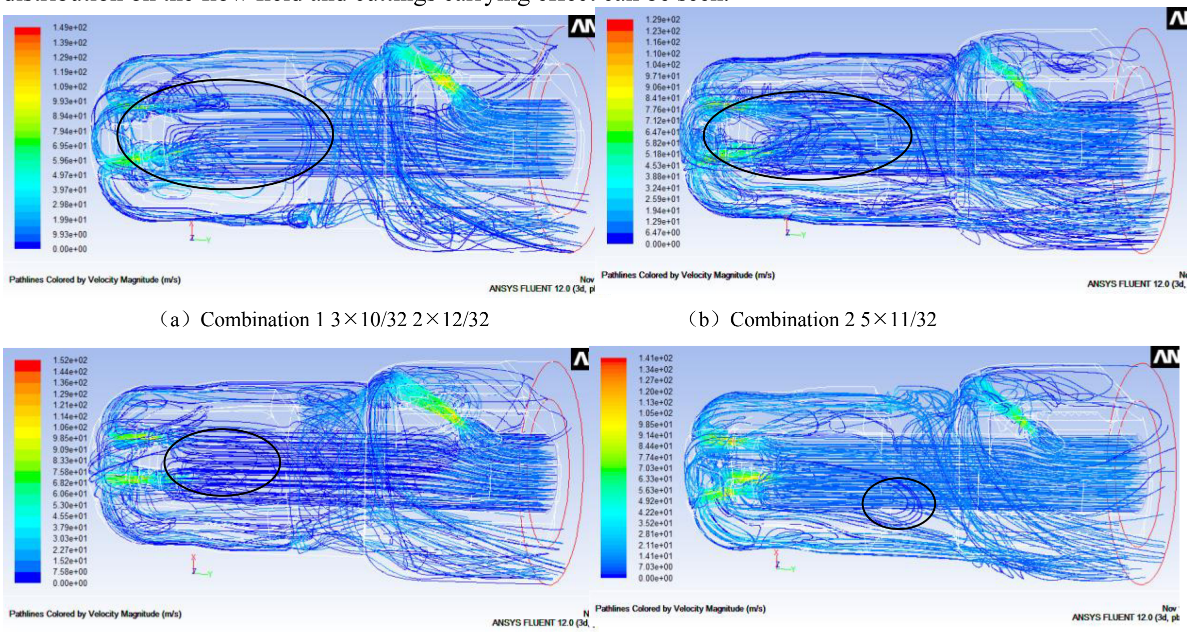
Flow distribution problem exists with the piloted section and the reaming section of a bi-center bit, different distribution plan will affect the degree of interference and the effect of cuttings carrying effect, and the distribution depends directly on the nozzles equivalent area of two sections, different distributions can be got by changing the combination of nozzles. To ensure the same pressure drop and hydraulic energy loss, total equivalent nozzle diameter of each combination should be similar.

Assuming that the piloted section has 3 nozzles, the reaming section has 2 nozzles, according to the equivalent nozzle diameter computation formula and the simulated well conditions, four nozzle combinations are as shown in Table 1.

Table 1 Nozzles size optimization data

Combination number	Number of nozzle	Size of nozzle(")	Total area of the nozzle mm^2			Equivalent diameter mm	Equivalent area mm	Pressure drop of bit Mpa
			Piloted section	Reaming section	Area ratio			
1#	5	3×10/32 2×12/32	149	142	1.05:1	19.25	291	1.8
2#	5	3×11/32 2×11/32	214	120	1.50:1	19.52	299	1.7
3#	5	3×12/32 2×10/32	214	99	2.16:1	19.95	313	1.56
4#	5	3×12/32 2×9/32	214	80	2.68:1	19.35	293	1.77

After simulating the bottom hole flow field model of each distribution option in Table 1 respectively, the streamline of each option is obtained, Fig. 5. Through the analysis of simulation results, the influence of the flow distribution on the flow field and cuttings carrying effect can be seen.



（a）Combination 1 3×10/32 2×12/32 （b）Combination 2 5×11/32

（c）Combination 3 3×12/32 2×10/32 （d）Combination 4 3×12/32 2×9/32

Fig. 5 Flow fields of different nozzle combinations

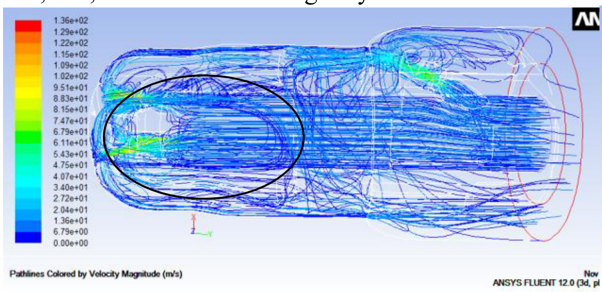
As shown in Fig. 5, the intersection interference occurs in transition section between piloted section and reaming section in four nozzles distribution options, disturbed by the flow from reaming section, the streamlines from piloted section generate a reflux.

With the gradual increase of the nozzles equivalent area ratio of the piloted section and reaming section, the reflux area is getting smaller, which means the disturbance is getting smaller as the flow distribution of the piloted section getting bigger, and the cuttings carrying ability is getting better.

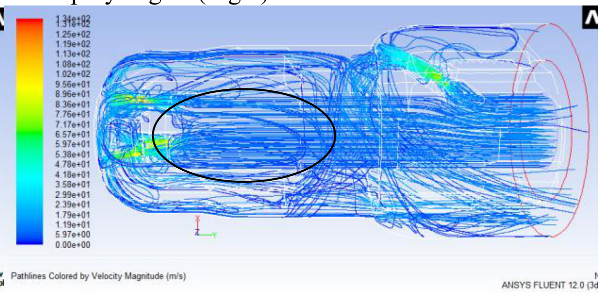
4.3. Influence of reaming nozzle spray angle

The piloted section of bi-center bit is similar to conventional bit, the flow from piloted section is disturbed by the flow from the reaming section, then generates a reflux, which could affect the cuttings carrying effect. Therefore studying on the relationship between reaming section hydraulic parameters and bi-center bit bottom hole flow field becomes particularly important. In the case of piloted section hydraulic parameters determined, this paper studies the influence of different nozzle spray angle by adjusting the nozzle spray angle of reaming section.

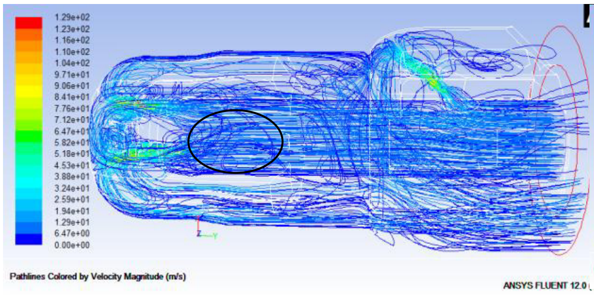
Reaming section nozzle spray angle is defined as the angle between the reaming section nozzle and the bit axis, in the case of the position of the nozzle is determined, in order to cover the whole bottom hole area, the range of the spray angle is 35°~50°. Therefore, keeping other hydraulic parameters unchanged, set the spray angle at 35°, 40°, 45°, 50°, the streamlines are got by simulation under different spray angles (Fig.6).



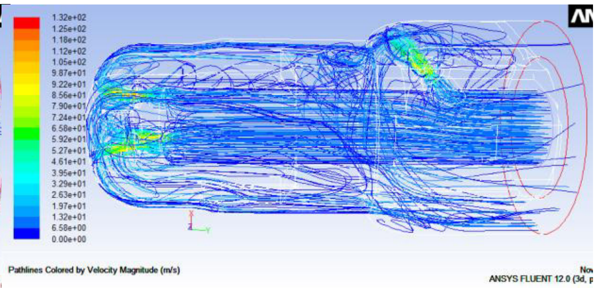
（a）Option 1 α=35°



（b）Option 2 α=40°



（c）Option 3 α=45°



（d）Option 4 α=50°

Fig.6 Streamlines under different spray angles

As shown in Fig.6, the reflux area is getting smaller with the reaming section spray angle increasing, when the spray angle is 50° almost no reflux occurs, which means that as the spray angle increases the up flowing fluid is increasing while the down flowing fluid is getting smaller, the interference of the flow from the piloted section is gradually reduced, and the cuttings carrying effect is getting better.

5. Optimization of bi-center bit hydraulic structure

5.1. Optimization of the flow distribution

After calculated, the rock breaking area ratio of the piloted section and the reaming section is 1.9:1, in order to keeping a good cuttings carrying effect the flow rate should be equal to the rock breaking area. According to Table 1, for option 3 (3 12/32 "piloted nozzles, 2 10/32" reaming nozzles), the equivalent nozzle area ratio between the piloted section and the reaming section is 2.16:1, which is closest to the rock breaking area ratio, to ensure adequate cuttings cleaning ability the most reasonable combination is option 3.

According to the relationship between flow distribution and the flow field, as the equivalent nozzle area ratio between the piloted section and the reaming section increases, the generated reflux area is getting smaller. As shown in Fig. 6, the reflux areas of option 3 and option 4 (3 12/32 "piloted nozzles, 2 9/32" reaming nozzles) are smaller than the other two options.

Therefore, based on the above factors, from the perspective of cuttings carrying, the optimal option is selecting 3 12/32 "nozzles for the piloted section, 2 10/32" nozzles for the reaming section.

5.2. Optimization of the reaming section nozzle spray angles

According to the relationship between the reaming section nozzle spray angle and flow field, the greater the reaming section nozzle spray angle, the smaller the reflux area. However, Fig. 7 shows that the reaming section spray angle of 50° is too large, which would directly jet into the borehole wall and cause hole enlargement, impact the wellbore quality. When the spray angle is 45°, the jet just impacts the central part of the reaming bottom, while the reflux area is smaller. Therefore, the optimal reaming section spray angle is 45°.

6. Conclusion

- Against features of bi-center bit bottom hole flow field, the evaluation method based on the flow distribution and the reflux area is proposed.
- Using FLUENT hydraulic analysis software, the flow field of bi-center bit are simulated under different flow distributions and different reaming section spray angles.
- To improve the cuttings carrying and clearing effect, an optimal bi-center bit design is proposed which is characterized by 3 12/32 "piloted nozzles, 2 10/32" reaming nozzles, reaming section spray angle at 45 °.

Acknowledgements

Supported by the national science and technology major special project: key technologies of complex structural well’s optimization design and control.

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